Title: Dark photon production in positron beam dump experiments via resonant annihilation

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Abstract:

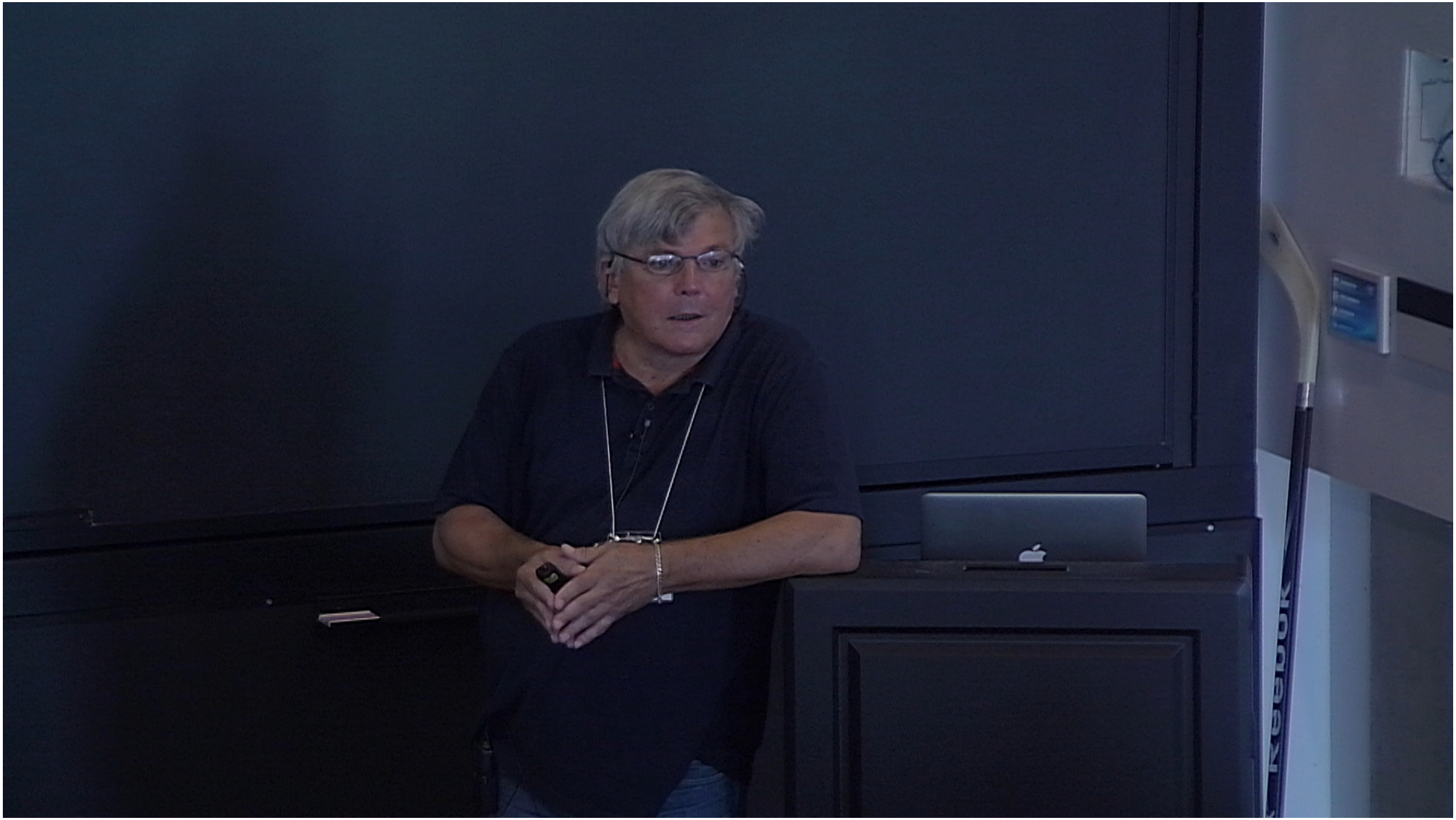
Dark photons production in e^+ beam dump experiments via resonant e^+e^- annihilation

Enrico Nardi

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

"New directions in dark matter and neutrino physics"

Perimeter Institute – July 20-22, 2017



We want to propose a new DP search technique, suitable for PADME@LNF
[Positrons Annihilation Dark Matter Experiments]

Outline:

- Beam dump experiments: Production modes for DP searches
- Proposal: production via resonant $e^+ e^- \rightarrow A'$ (peculiarities and advantages)
- A specific goal: testing the Atomki ^{8}Be anomaly and the 17MeV DP explanation

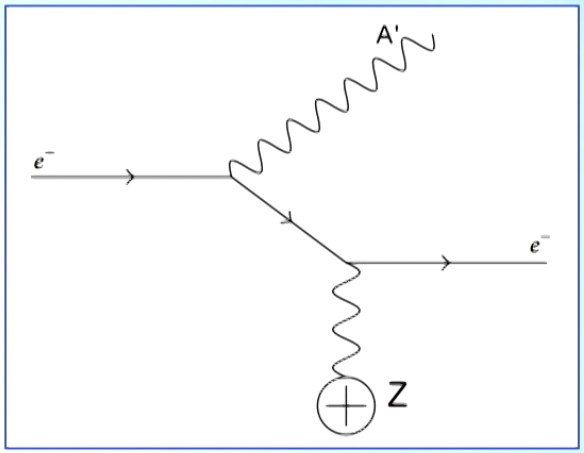
Inputs: C.D. Ruiz Carvajal (UdeA), A. Ghoshal (RM3), V. Kozhuharov (U. Sofia),D. Meloni (RM3), M. Raggi (RM Sapienza)

Fixed target experiments for DP searches

Electron beams fixed target experiments:
Electron scattering off nuclei: A' bremsstrahlung

$O(\alpha^3)$ process

A' production via electron bremsstrahlung:
APEX,HPS,DarkLight (JLab) A1, MAGIX (Mainz),
NA64 (CERN), (SLAC), (Cornell)...



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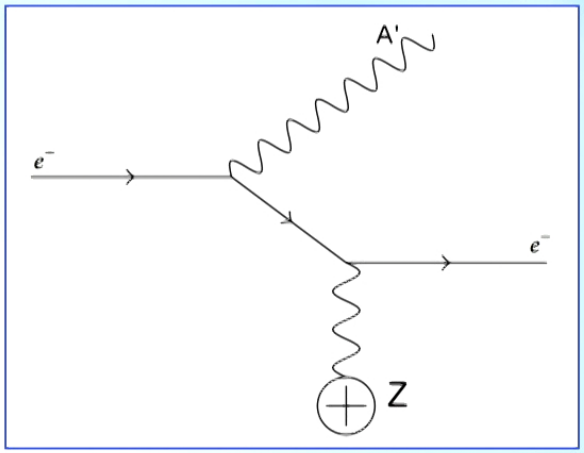
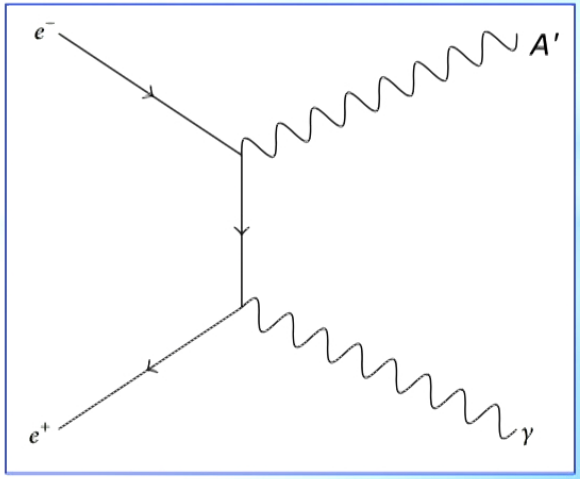


Positron beams fixed target experiments:
Positron-electron 2-body annihilation $e^+ e^- \rightarrow A' \gamma$
[analogous of $e^+ e^- \rightarrow \gamma \gamma$]

$O(\alpha^2)$ process

Positron beam experiments [proposed]:
VEPP3 (BINP), PADME (LNF), [MMAPS (Cornell)]



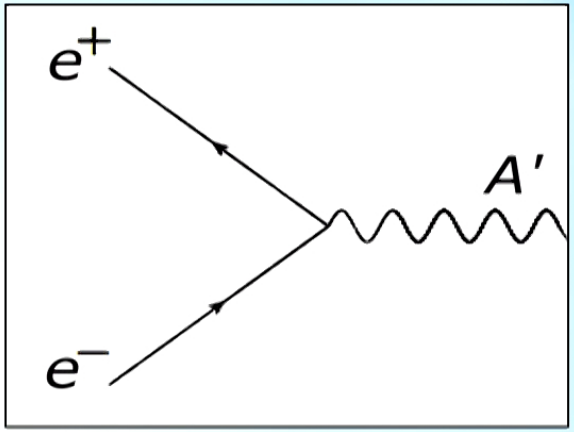
Fixed target experiments for DP searches

PROPOSAL:

Positron-electron **resonant** annihilation $e^+ e^- \rightarrow A'$

[analogous of $e^+ e^- \rightarrow Z$]

O(α) process



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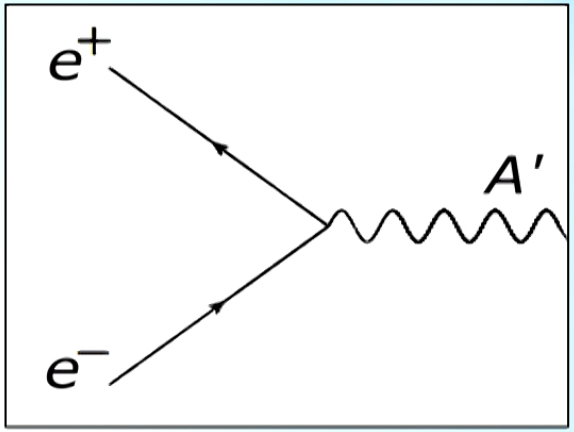
[analogous of $e^+ e^- \rightarrow Z$] O(α) process

However: $\Gamma_Z = 2.5$ GeV, $\Gamma_{A'} \sim 10^{-3} - 10^{-4}$ eV

Because of the continuous energy loss of positrons when propagating through matter, positrons "scan" downward in energy until hitting the resonance



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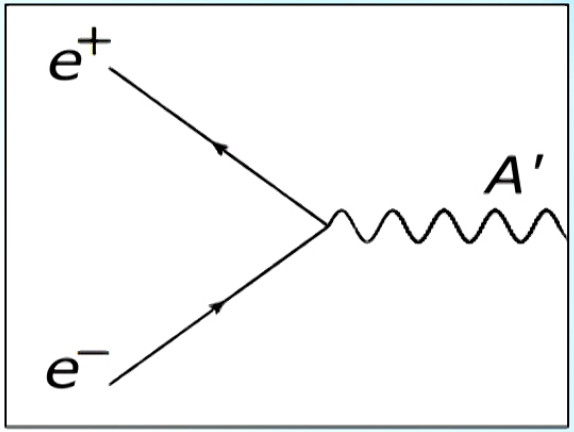
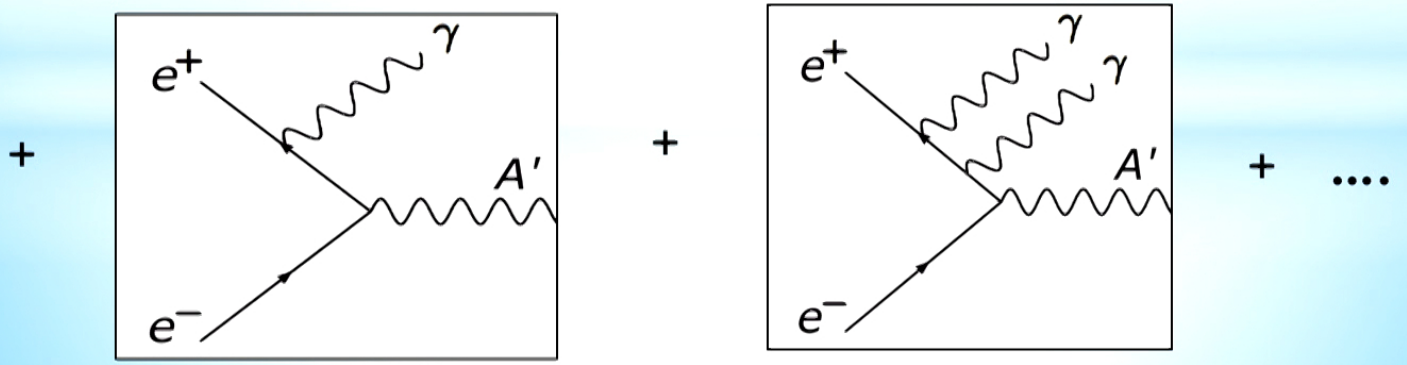
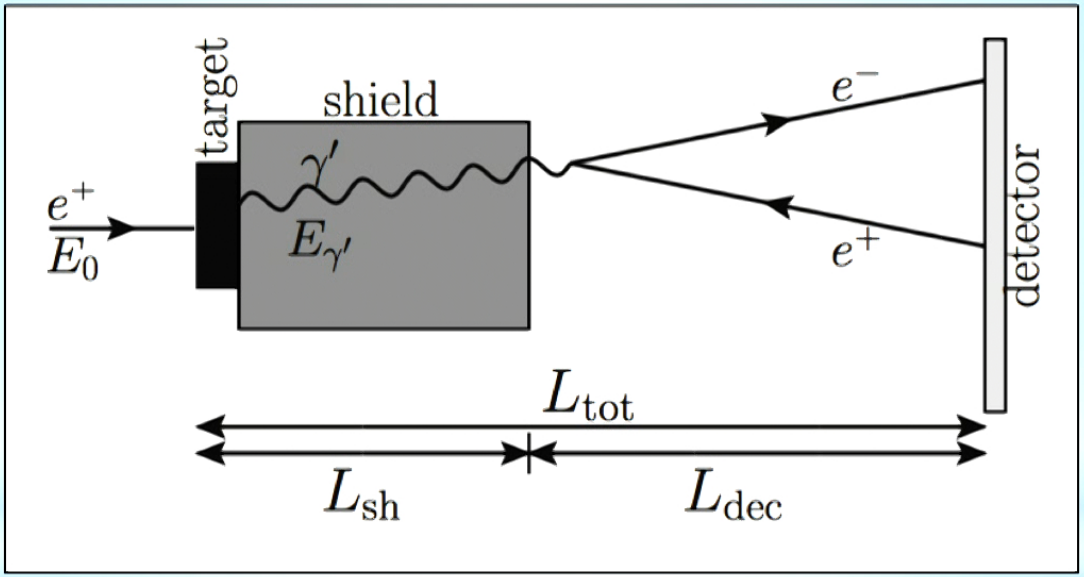


"Radiative return" also helps enhancing the x-section by "widening" the resonance:



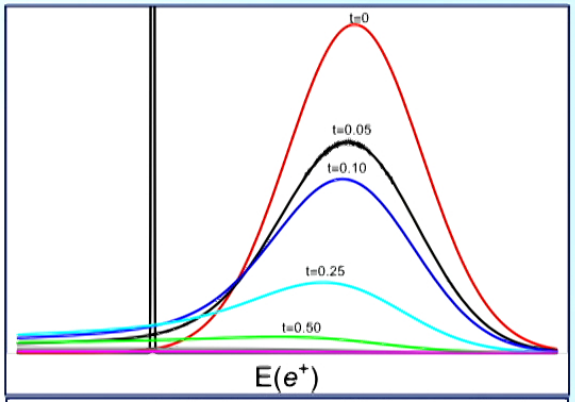
Sketch of the setup of a positron beam dump experiment
(Adapted from electron bremsstrahlung A' production)

S. Andreas et al. PRD86,095019 (2012)



Resonant A′ production: peculiarity & advantages

- Almost continuous scan in energy: ΔE~10 eV per single ionization (ΔE~10 MeV for $1X_0$ in $_{74}W$)



e⁺ energy distribution vs. radiation length *t*

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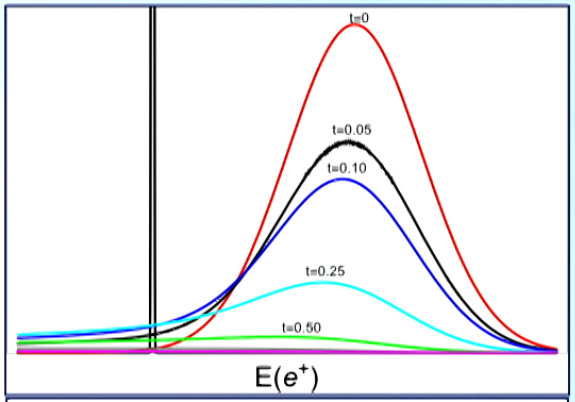

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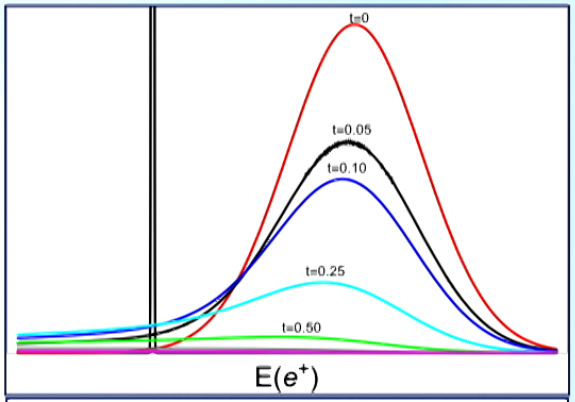

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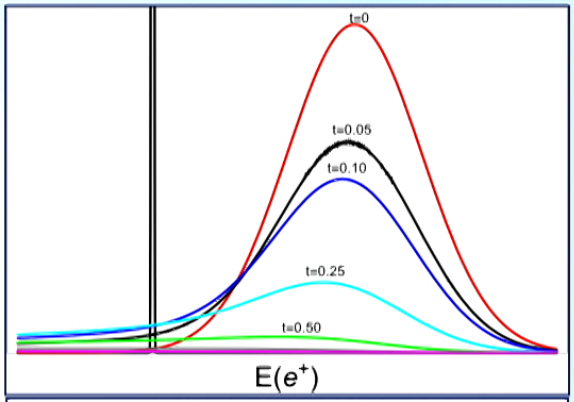
- Background can be directly obtained from data collected below the resonance



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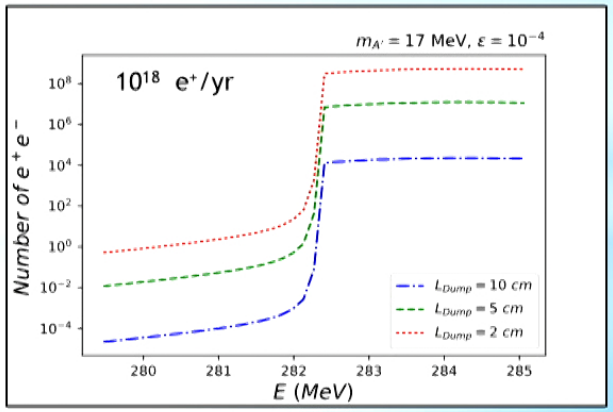


Resonant A' production: peculiarity & advantages

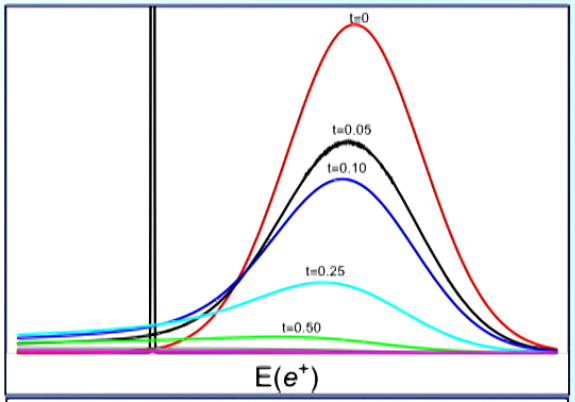
- Almost continuous scan in energy: ΔE~10 eV per single ionization (ΔE~10 MeV for $1X_0$ in $_{74}W$)

- Resonant $e^+ e^- \rightarrow e^+ e^-$ production only mildly dependent on ε: $\sigma_{res} \sim 1/m^2_{A'}$ ($\Gamma_{A'} \propto \varepsilon^2$)

- To an excellent approx. decay length $L_D = \gamma\, c\, \tau$ independent of $m_{A'}$: $L_D = (m_{A'}/2m_e)(1/\Gamma_{A'}) \propto 1/m_e$

- Background can be directly obtained from data collected below the resonance

- Enhancement of A' production from resonance broadening due to Fermi motion of free conduct. electrons (E_F^W = 4.5 eV, $n_e = 4.3\times10^{28}$ m^{-3})
(not yet estimated)



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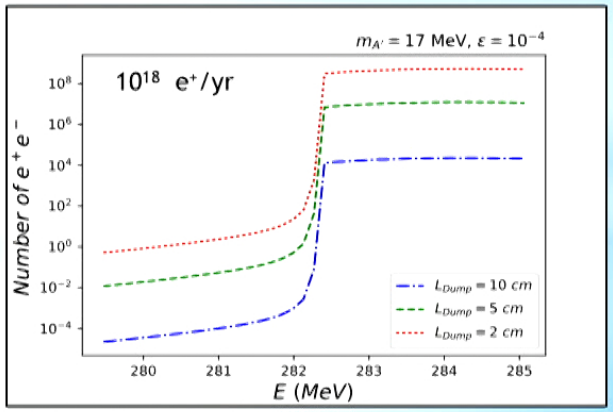

Comparing A' production modes

Frascati DAΦNE BTF: number of $e^{-(+)}$/yr: 10^{18} (LNF site authorization limited)

2×10^{20} ($1.2 \times 10^{11} \times 50 \times 3.15 \times 10^{7}$ technically faisable)

$m_{A'} \leq$ 24 (28) MeV

$m_{A'} \geq$ 16 MeV

E_{max} (e^-/e+): 800 MeV/550 MeV (upgrade: 1050 MeV/800 MeV)

E_{min} (e^-/e+): 250 MeV

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Comparison: A' produced for $m_{A'}$ = 17 MeV; $\varepsilon = \sqrt{\alpha'/\alpha} = 10^{-4}$; E_b = 550 MeV

Production mode	E_{beam} (MeV)	T [integration]	A' produced
Bremsstrahalung (e^-)	550	0.5	4.1×10^7
Annihilation (e^+)	550	0.5	8.7×10^8
Resonant (e^+)	E_{res}=282 MeV	[0 - 0.5]	8.1×10^9
Resonant (e^+)	$E_{res} + 2\sigma_{beam}$	[0 - 0.5]	13.2×10^9

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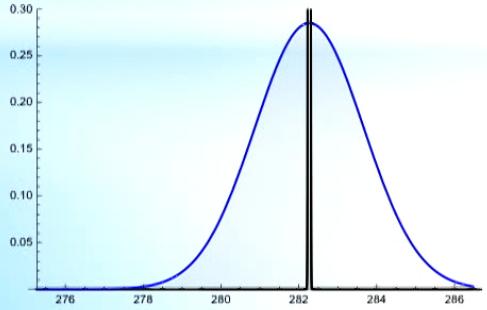
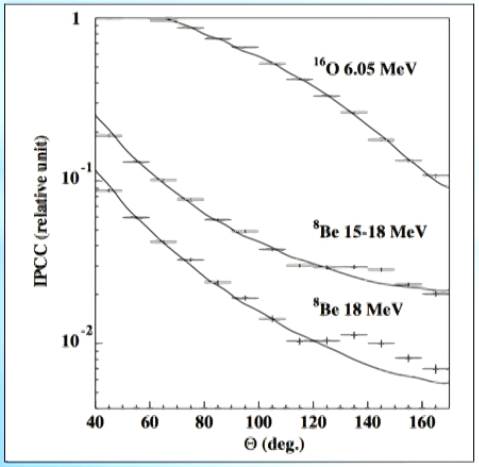


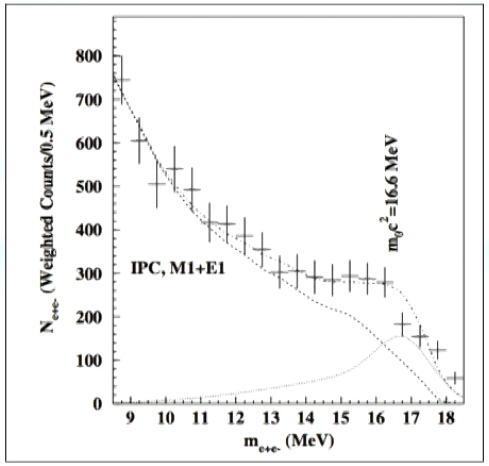
The Atomki anomaly in ^{8}Be nuclear decays (6.8 σ)

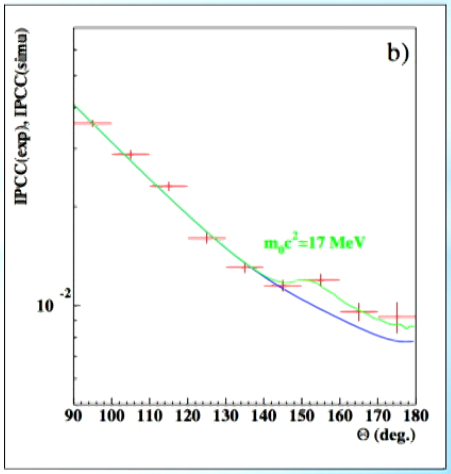
A. Krasznahorkay et al. PRL117,071803,2016

The Atomki collab. has observed unexpected bumps in $^8Be^* \rightarrow {}^8Be\ e^+ e^-$ decays:

	18.15 MeV $^8Be^*$ state	17.64 MeV $^8Be^*$ state
(i) e^+e^- opening angles	$\theta \approx 135°$	$\theta \approx 155°$
(ii) e^+e^- invariant masses	$m_{e+e-} \approx 16.7 \pm 0.35 \pm 0.5$ MeV	$m_{e+e-} \approx 17.0 \pm 0.2 \pm 0.5$ MeV







Anomaly consistent with decays via A' gauge boson

$^8Be^* \rightarrow {}^8Be\ A' \rightarrow {}^8Be\ e^+ e^-$

Summary of the (constrained) A' parameters:

J.L.Feng et al., PRD95, 035017 (2017)

Mass: $m_{A'} \approx 17.0 \pm 0.5$ MeV

Coupling strengths ($\times\alpha$): $\varepsilon_n \approx (2\text{-}10) \times 10^{-3}$

$\varepsilon_p \lesssim 1.2 \times 10^{-3}$ [constrained by $\pi \rightarrow A' \gamma$]

[Beam dump E141] 2×10^{-4}

[ORSAY] 6×10^{-5}

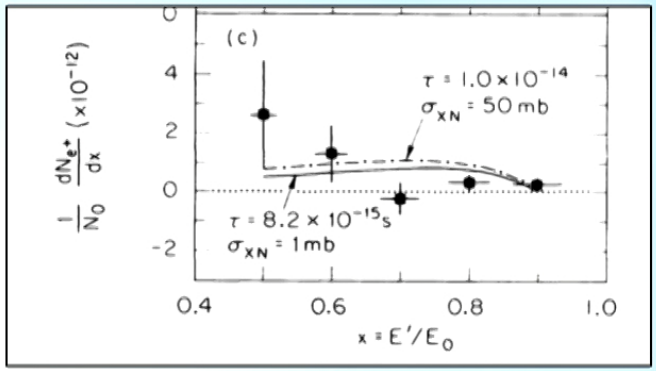
[KEK] 5×10^{-5}

$\lesssim \varepsilon_e \lesssim 1.4 \times 10^{-3}$ [$(g\text{-}2)_e$ and KLOE ($e^+ e^- \rightarrow A' \gamma$)]

S.Andreas, C.Niebuhr, A.Ringwald, PRD86,095019 (2012)

Questioning the limit from E141

Limit derived in S. Andreas et al. PRD86,095019 (2012) confronting data from the E141 paper (E.M. Riordan et al.. RL59 7,755 - 1987) and with cross-sections computed adopting the Weizsacker-Williams approximation.



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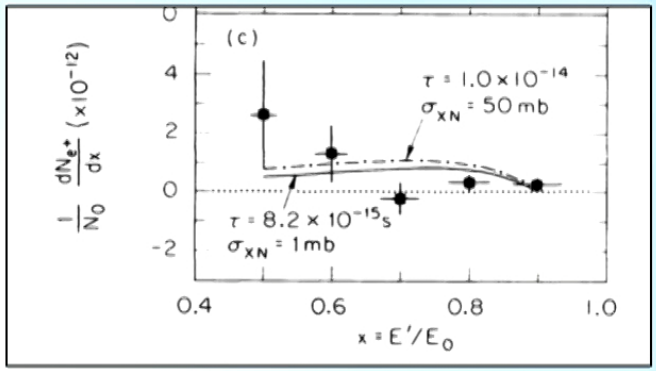

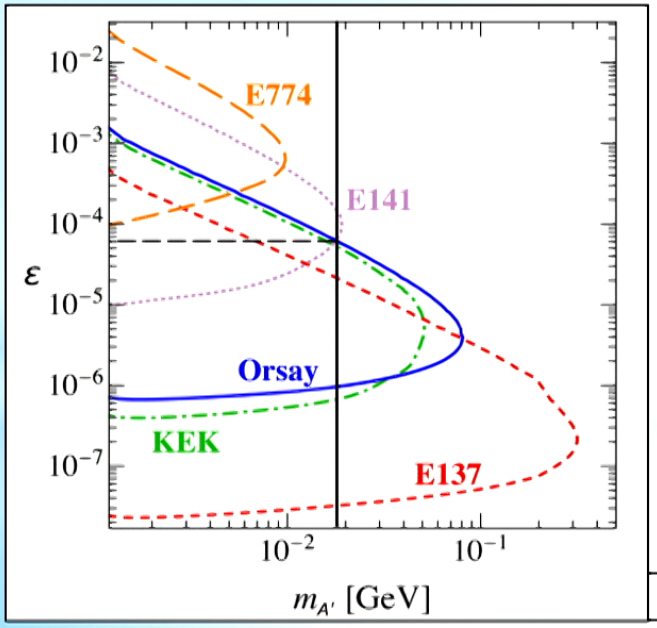

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For $m_{A'} \approx 17$ MeV the E141 constraint is close to the mass reach limit, and thus sensitive to any approximations in the phase space integrations

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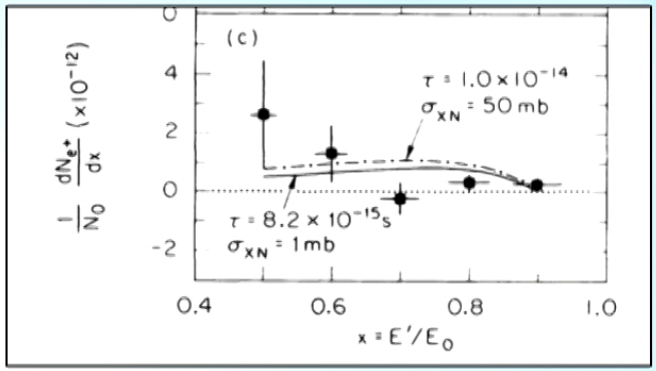

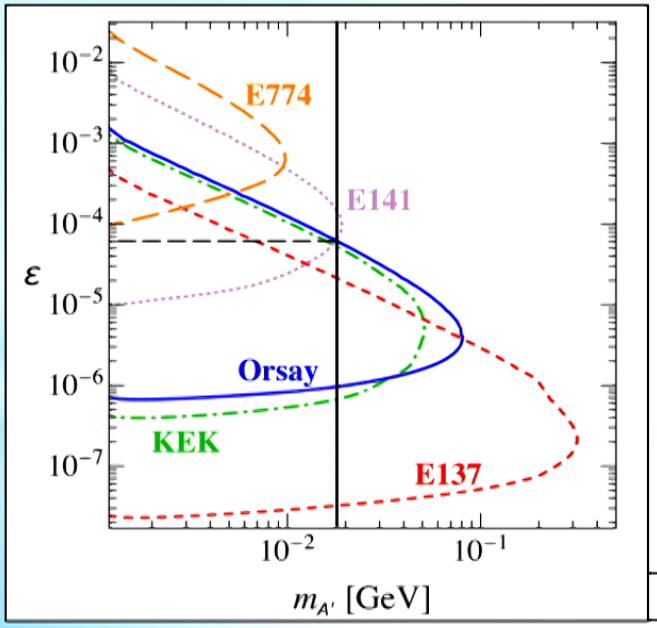

S. Andreas et al. PRD86,095019 (2012)

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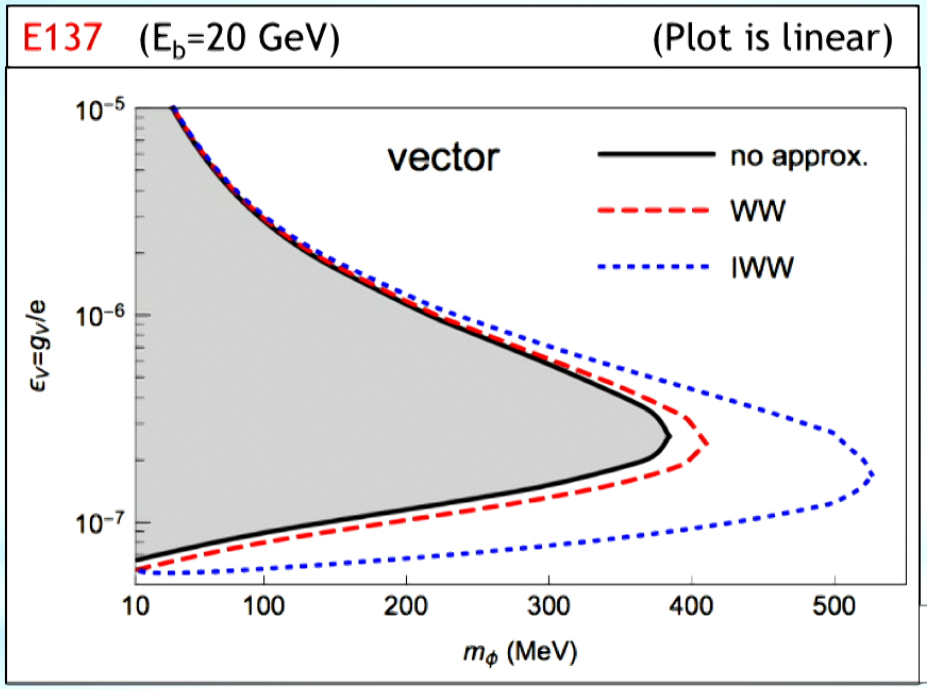
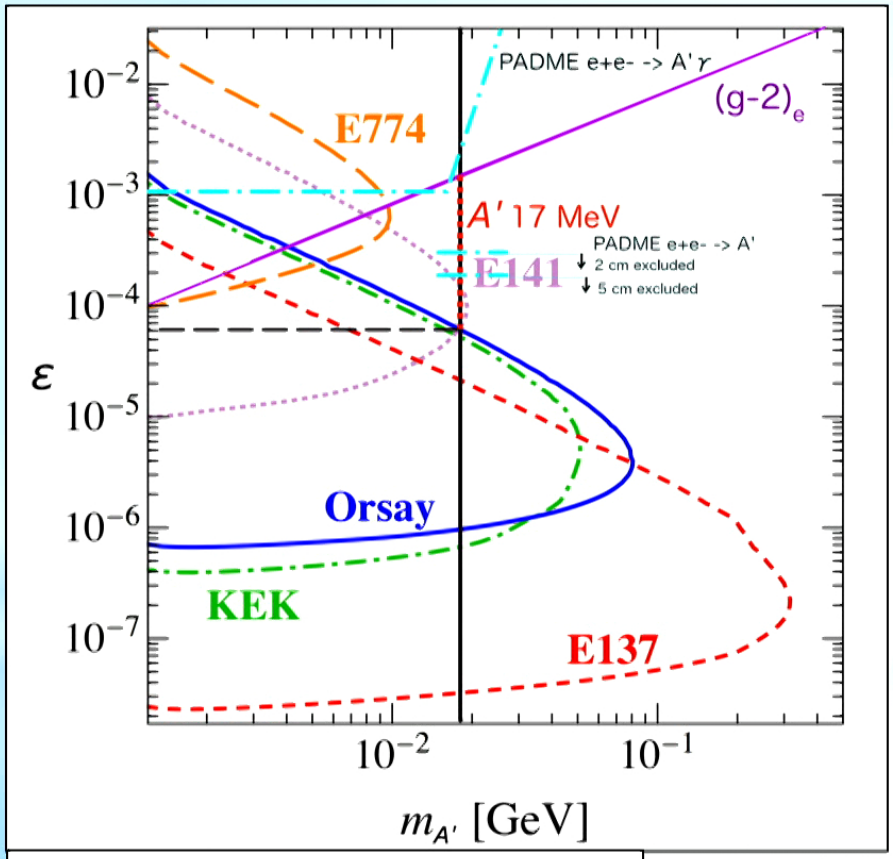
Questioning the limit from E141

The validity of the WW approximation has been recently studied in *Yu-Sheng Liu and G. A. Miller PRD96 (2017) 1, 016004.* Results have been applied to the E137 limit (E_b=20 GeV)



Yu-Sheng Liu and G.A. Miller
PRD96 (2017) 1, 016004

The PADME reach with $e^+ e^-$ resonant annihilation



Adapted from S. Andreas et al. PRD86,095019 (2012)

Reach in mass:
16 MeV < $m_{A'}$ < 24 (28) MeV

$\varepsilon_e \gtrsim 1.9 \times 10^{-4}$

With 5 cm tungsten-dump
(presumably background free)

$\varepsilon_e \gtrsim 3.0 \times 10^{-4}$

With 2 cm tungsten-dump
(if background under control)

PADME exclusion reach in the original $e^+ e^- \rightarrow A' \gamma$ mode is also shown (top left corner)

In conclusion:

(Quotes in color are from the workshop webpage)

We want to propose a new creative use of a planned facility (PADME@LNF) and an alternative method of probing new physics (DP) at high-intensity accelerators (BTF@LNF)

Thanks for your attention
Comments/suggestions are most welcome